INNOVATIVE REACTIVE BARRIER TECHNOLOGIES FOR REGIONAL CONTAMINATED GROUNDWATER

Peter Merkel[1,2], Holger Weiß[2], Georg Teutsch[1], H.H.M. Rijnaarts[3]

[1]University of Tübingen, Geological Institute, Germany
[2]UFZ Centre for Environmental Research Leipzig-Halle, Dept. Industrial and Mining Landscapes
Permoserstraße 15, D-04318 Leipzig, Germany
[3]TNO Env., Energy and Process Innovation, Apeldoorn, The Netherlands

Key words: reactive barriers, chlorinated hydrocarbons, clean-up technologies, groundwater clean-up, in-situ groundwater remediation, pilot plant, brownfields

Summary

At many industrial sites inadequate waste disposal, leakages and war damages have led to severe groundwater contamination on a regional scale. Standard hydraulic groundwater remediation methods, such as pump-and-treat, in most cases do not lead to satisfactory results, due to the persistence of organic contaminants and the resulting very long remediation times.

The goal of SAFIRA (**Sa**nierungs-**F**orschung **i**n **r**egional kontaminierten **A**quiferen), a joint project of several research partners is to develop and to provide the necessary technologies and methods to demonstrate the successful implementation of in situ reactive barriers in regionally contaminated aquifers.

In this joint project German and Dutch research partners co-operate in developing treatment zone technologies based on various chemical and biological processes. The SAFIRA on-site underground reactor facility in Bitterfeld is used for investigations under in-situ aquifer conditions.

Here 8 principal approaches are being tested and evaluated with respect to their technical and economical performance. In addition to the development of reactor technology various other aspects of passive in situ treatment such as legal, economical and ecological aspects are addressed by several research groups including the Umweltforschungszentrum Leipzig-Halle, as well as the universities of Tübingen, Dresden, Kiel, Leipzig, Halle and TNO.

1 Introduction

Approx. 75 % of the drinking water in Germany is extracted from available groundwater resources. For this reason the protection of this essential resource is of a special interest. At many industrial sites in Germany inadequate waste disposal, leakages and war damages have led to the contamination of the subsurface with various contaminants, which in some instances led to groundwater contamination on a regional scale.

The experiences of the last 20 years show, that standard hydraulic soil and groundwater remediation methods, such as pump-and-treat, in most cases do not lead to satisfactory results. This is even more true for large scale subsurface contamination, where the source area of the contamination can either not exactly be localised or not be readily removed.

In order to avoid a permanent extraction and the subsequent treatment of contaminated groundwater, intensive research efforts in the last years have concentrated on the development of cheaper innovative in situ technologies which focus on the removal or the degradation of contaminants in the aquifer. In contrast to 'active' technologies, which mainly focus on the source areas, 'passive' technologies are characterised by little or virtually no energy input during the remediation measure. Passive technologies have the advantage that operation costs, during the inevitably long remediation times, can be drastically reduced. The most advanced type of passive remediation techniques are in situ reactive barriers. For single contaminants or simple contaminant cocktails (e.g. PAH or VOC) reactive barriers are already implemented at several sites.

This new approach of addressing the contaminant plume instead of the source area offers significant advantages, if the longevity of passive in situ reactors can be maintained at low operation costs over long time periods. In this context the treatability of complex contaminant cocktails is the major research aim, as these are often encountered at former sites of chemical industries in the new German states as well as in Eastern Europe.

One example of a regional contamination of an aquifer is the Bitterfeld industrial complex in Saxony-Anhalt, Germany. For more than 100 years the activities in open cast lignite mining and the related chemical industries have had a serious impact on soil and groundwater quality. While the soil contamination is generally limited to the premises of the former industrial sites and landfills, the groundwater has regionally been contaminated over an area of approx. 25 km^2 with a total volume of approx. 200 million m^3.

2 The SAFIRA project

The goal of SAFIRA (**Sa**nierungs-**F**orschung **i**n **r**egional kontaminierten **A**quiferen), a joint project of several research partners is to develop and to provide the necessary technologies and methodologies to demonstrate the successful implementation of in situ reactive barriers in regionally contaminated aquifers. The Bitterfeld–Wolfen region was chosen as an example of an area with a large scale and complex groundwater contamination.

Due to the extended time frame of field testing and the yet limited knowledge about the economical factors involved, the SAFIRA research project, in contrast to many other research projects, compares several potentially successful groundwater treatment technologies concomitantly. Research groups from the UFZ Leipzig, as well as the universities of Tübingen, Dresden, Kiel, Leipzig and Halle are involved in a joint research effort sponsored by the Federal Ministry of Science and Education (BMBF).

Within the framework of the remediation research program of the UFZ Leipzig there are also links to several international co-operation partners. Among them is a consortium from the Netherlands, led by TNO, with Tebodin, HBG/HWZ and Shell as partners. The Dutch research is supported by NOBIS (Netherlands Research Programme for Biological In Situ Remediation), and its succession, SKB (The Netherlands programme on Knowledge Development and Transfer on Soil Quality Management).

In order to address all important aspects of this innovative remediation approach the SAFIRA project is subdivided into several thematic branches. In addition to the aspects of scientific-technical implementation, economical evaluation as well as subsequent land use and legal aspects are being addressed. In the scope of the project, special emphasis is put on the possibility that innovative approaches and at least parts of the results obtained by the individual research partners can be transferred to other contaminant scenarios in and outside of Germany.

The overall aim of the research project includes:

- the development and the successive implementation of innovative low energy or passive water treatment technologies for mixed organic groundwater contamination from prototypes to full-scale technical in situ application,
- the technical-economical optimisation of the individual technologies as well as possible combinations including the structural aspects of their implementation in in situ reactive barriers,
- the demonstration of the longevity of the new technologies in the field and the determination of their actual operation cost,

- the assessment of the legal and ecological aspects of the implementation of a reactive barriers system, exemplary for the Bitterfeld Region,
- the development of economical application strategies for the most promising technologies.

3 The SAFIRA structure

SAFIRA is subdivided into several thematic research branches, each including related research projects. One branch (A) is responsible for the operational and logistical project management for the in situ reactors. Branches B and C concentrate on the research on innovative reactor technologies and natural occurring in situ processes at the site. Branch D takes into account the ecotoxicological aspects of in situ reactive systems and branch E covers the general environmental impacts of the implementation of a reactive barrier in the field.

Tab. 1. SAFIRA Project Structure (detailed titles of the individual projects are listed at the end of this text)

A	**Site management and analytic**	
	A1	Project and test site management
	A2	Determination of metabolites of in situ technologies
B	**Reactive treatment technologies**	
	B1	Activated carbon technology
	B2	Microbiological technologies and processes
	B3	Catalytic technologies
C	**Modelling**	
	C1	Aquifer modelling
	C2	Immission modelling
D	**Ecotoxicology**	
E	**Environmental and economical aspects**	

Branch B of the SAFIRA project includes 3 different types of technologies for the in situ decontamination of polluted groundwater

1. Methods based on the sorption of organic contaminants on *activated carbon* possibly in combination with bioreactors or used in multi-reactor systems, in order to increase the longevity and the applicability on complex contaminant cocktails.
2. Methods based on the *microbiological degradation* of organic contaminants, using the autochthonous anaerobic microflora, as well as the application of stimulated anaerobic and aerobic degradation of aromatic and aliphatic compounds.

3. The third type of technologies is based on *electro-chemical principles*, or uses innovative *technical catalysts*, respectively. Due to the potentially small reactor unit sizes and their low operational costs, catalyst-based technologies could be an economically interesting alternative, if a sufficient longevity of the reactors can be guaranteed.

With the exception of the reactor technology using activated carbon, non of the planned technologies are passive systems in a strict sense. Especially the third reactor type needs constant energy or additive input (e.g. H_2-as a reductant). Nevertheless the related costs can possibly be very low considering the reduced investment costs for smaller reactor units compared to a full scale implementation of a reactive barrier system. The simultaneous operation of several reactor technologies at one site allows an immediate comparison of their technical and economical performances.

4 Preliminary Results

So far the project was characterised by the pre-selection of generally suitable treatment technologies and an evaluation of their possible applicability to Bitterfeld groundwater in laboratory and in on site experiments. These tasks and the site evaluation were performed in a one year preliminary study.

Within the framework of these preliminary studies the technical feasibility of the project could be proven on the basis of a detailed hydraulic, hydrogeochemical and microbiological investigation of the site along with especially tailored laboratory experiments. For small scale on site experiments an air-conditioned mobile reactor unit was equipped with 1 m columns which made it possible to perform experiments at groundwater monitoring wells on site under close to normal in situ conditions. Based on either their successful performance in the mobile reactor or on promising first results in lab experiments the following 8 approaches were selected to be tested in large scale in situ application:

1. Biodegradation of chlorinated hydrocarbons in a sequential anaerobic/micro-aerobic system
2. Adsorption and simultaneous microbiological degradation of chlorinated hydrocarbons on activated carbon
3. Degradation of chlorinated hydrocarbons using palladium coated Y-zeolites
4. Oxidizing metal catalysts
5. Membrane supported palladium catalysts
6. Redox-combination reactors
7. Activated carbon filtration
8. Anaerobic microbiological degradation of contaminants

5 The SAFIRA pilot facility

One important aspect of the SAFIRA concept is the in situ pilot facility, which has to guarantee that the selected treatment technologies can be tested under realistic in situ conditions. The pilot facility in Bitterfeld, which houses a total of 20 reactors, consists of 5 shafts with a depth of 23 m, a diameter of 3 m and a shaft-to-shaft distance of 19 m, which were placed in a line perpendicular to the local groundwater flow direction and an on site laboratory building. Construction at the site was completed in March 1999 and the pilot facility was officially opened in fall 1999.

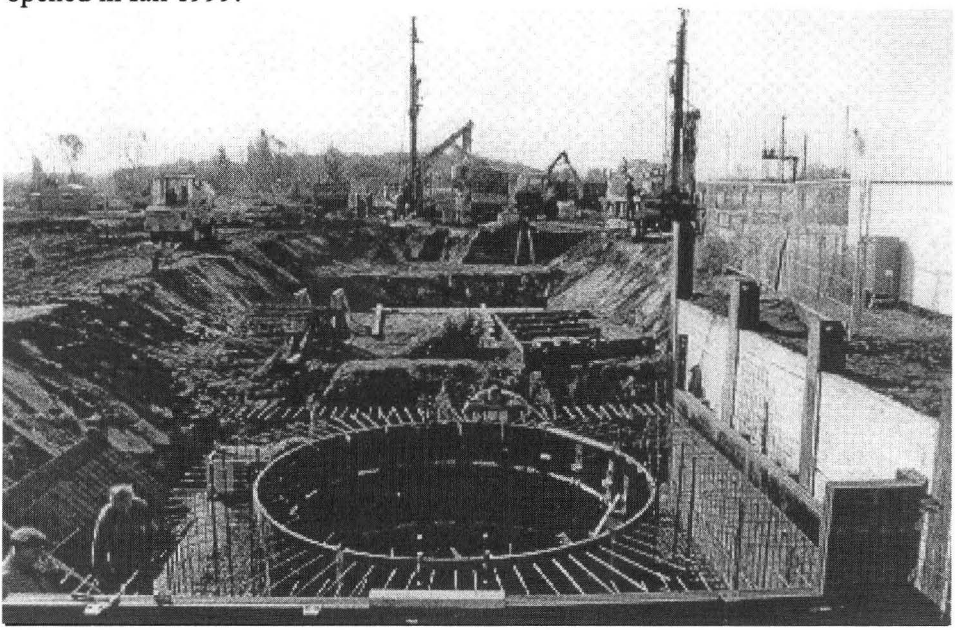

Fig. 1. Excavation and foundation work at the SAFIRA test site

The technical equipment and the design of the various reactors was planned and implemented according to the needs of the research groups. In order to meet the various requirements regarding the size of the reactors a modular set-up using single reactor segments, that are connected by flexible pipe systems was chosen (Fig. 2.).

Depending on the technologies of interest the sizes of the reactors range from 1-6 m in length and 150-1400 mm in diameter (see Figs. 2-3). The reactors are designed for a permanent system pressure of 3 bars and are operated in a flow-through mode from bottom to top. Flow rates can be varied, up to 400 l/h.

The groundwater for each shaft is collected by 2 horizontal wells of 10 m of length which were drilled at an angle of 60°. The on site laboratory analyses the

Fig. 2. Installation of a reactor (length 2,5 m, diameter 1,4m)

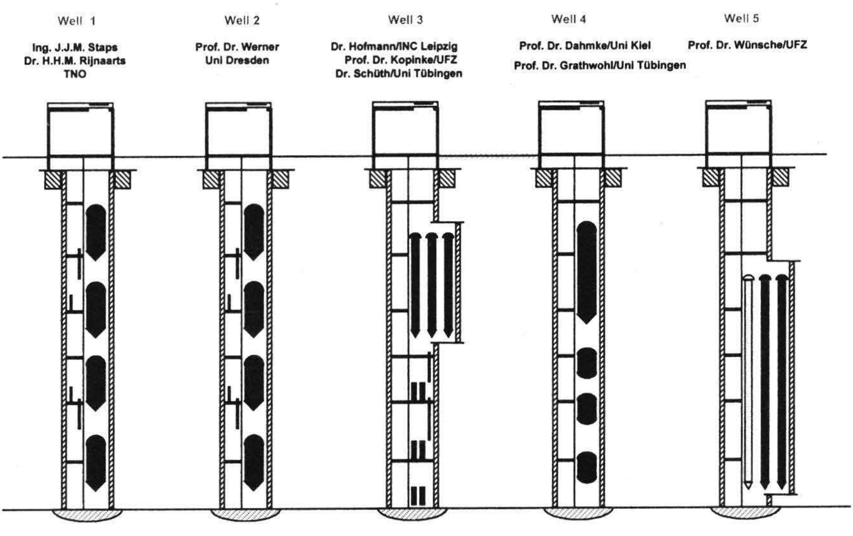

Fig. 3. Schematic illustration of the SAFIRA in situ pilot facility showing the modular reactor set-up and the respective research groups

major contaminants as well as the physical-chemical parameters (pH, conductivity, redox potential, temperature and oxygen content) AOX, TOC, and DOC directly at the site, thus minimising possible alterations of the samples due to transport and storage.

6 Outlook

Over the next years the SAFIRA project will offer the unique opportunity to evaluate several promising in situ technologies under large scale treatment conditions. Due to its broad approach, that includes technical as well as ecological and economical aspects, the SAFIRA project will provide the necessary tools to evaluate the applicability of in situ remediation systems for various site conditions.

References

Weiß, H. Teutsch, G. Daus, B. (eds.) (1997) Sanierungsforschung in regional kontaminierten Aquiferen, UFZ Bericht Nr. 27

Weiß, H. Daus, B., Teutsch, G. (eds.) (1999) SAFIRA, 2. Statusbericht Modellstandort, Mobile Testanlage, Pilotanlage, UFZ Bericht

Report of the november 1999 workshop, UFZ Bericht, In press

Van Eekert, M.H.A, Staps, J.J.M.,. van Heiningen, W.N.M, Hetterschijt, R., Visser, E.,. Mol J.J.W, Rijnaarts, H.H.M (In press) Bitterfeld: Bioremediation of regionally contaminated aquifers, Phase I and II.. NOBIS-report, CUR-NOBIS, Gouda, The Netherlands

Appendix

Scientific/technological approaches and related research contacts

Scientific/technological approaches	Research contacts
Project and test site management	weiss@pro.ufz.de georg.teutsch@uni-tuebingen.de
Determination of metabolites and degradation products of in situ technologies	weiss@pro.ufz.de
The Influence of Groundwater Specific Parameters on the Performance of In Situ Reactors based on the Example of In-Situ Activated-Carbon-Filtration	peter.grathwohl@uni-tuebingen.de
Elimination of volatile organic compounds by adsorption and simultaneous microbiological degradation on activated carbon	pwerner@arcs.urz.tu-dresden.de

Development of coupled in situ - reactors and optimisation of the geochemical processes downstream of different in situ - reactor systems	ad@gpi.uni-kiel.de
Microbiological in situ remediation of aquifers contaminated with chloroorganic contaminants at the model site Bitterfeld using autochthonous bacteria	wuensche@umb.ufz.de
Dechlorination of chlorohydrocarbons in groundwater by electrochemical and catalytic reactions	kopinke@san.ufz.de
Zeolite-supported catalysts for hydrodehalogenation of contaminants in groundwater	schueth@uni-tuebingen.de
Degradation of halogenated organic pollutants by ultrasound-assisted catalytic oxidation	jhofmann@sonne.tachemie.uni-leipzig.de
Reactive transport in technical reactors	rudolf.liedl@uni-tuebingen.de
Direct oxygen injection into natural aquifer sections and artificial porous media: Gas-water-dynamics and heterogeneous reactions between mixed fluid phases	geist@hdg.ufz.de
Determination of the contaminant loads in contaminated aquifers for the design of in situ reactors	thomas.ptak@uni-tuebingen.de
Ecotoxicological determination of the performance of in situ treatment measures in contaminated aquifers	ra@uoe.ufz.de
Development of model approaches to assess the general effects of groundwater remediations by permeable reactive barriers	wycisk@geologie.uni-halle.de
Technical and environmental-econonmical assessment of reactive barriers	georg.teutsch@uni-tuebingen.de
Biodegradation of chloroethenes and chlorobenzenes in a two-phase anaerobic/microaerobic treatment zone system	s.staps@mep.tno.nl h.h.m.rijnaarts@mep.tno.nl